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HYDRO POWER AND COMPARATIVE TURBINE PERFORMANCE EVALUATION

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ABSTRACT

This paper presents a review of development of hydro power, its basics, teaching and performance evaluation. The laboratory experimental data pertaining to Pelton, Francis and Kaplan small turbines has been analysed. The analysis presented here is based on turbine shaft load resulting in utilization of water power and includes comparative overall efficiency, specific speed and unit quantities based on data is presented.

KEYWORDS: Hydro Power, Classification, Turbines, Performance Evaluation, Experimental Data

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Original Article

INTRODUCTION

The term hydro power means generation of mechanical power from falling water. The power then can be used for direct mechanical applications or for generating electricity. Hydropower presently accounts for 20% of world's total electric power generation. [1].

Other resources such as solar, wind, geothermal and tidal energy were also explored. These are green and renewable and have no adverse effect on environment. These are produced continuously and therefore inexhaustible. In fact hydro power is also an outcome of abundant solar power and water. Possibility of using hybrid of hydro, solar and wind power are also being attempted [2, 3, 4, 6]. Among these hydropower is the oldest and was in use during agriculture based society [5].

The development of hydro-electricity in the 20th century required building of large dams. These have also resulted in environmental problems due to the interference with river flows.

The current focus is on small or micro hydro power generation as they do not require massive construction. Small-scale hydro is generally a "run-of-river", with no dam or water storage. It is cost-effective and environmental friendly energy technology [7]. Hence several "run-of-river" schemes are found on the downstream end of the large storage reservoir schemes. The large reservoir project can regulate the output of these small "run-of-river" plants. These schemes are considerably cheaper as little construction is required. [6, 8].

Classification

Following table gives the classification of hydro power plants. It is based on capacity and worldwide practice [7, 10].

Table 1: Classification Based on Capacity

Type	Capacity
Large Hydropower Plants	> 25 MW
Small Hydropower plants (SHPPs)	2.5 MW – 25 MW
Micro Hydropower plants (MHPPs)	< 500 KW
Pico Hydropower plants	Below 10 KW

The energy conversion is through the prime mover known as hydro turbine. Hydro turbines convert water energy into mechanical energy.

History of Hydraulic Turbines

Hydro power started with the wooden waterwheel. Waterwheels had been in use in many parts of Europe and Asia for some 2,000 years, mostly for milling grain [7]. During 17thcentury industrial revolution started and hydro power got a boost and lead to the development of modern day turbines. Benoît Fourneyron designed the first hydraulic turbine in France in 1820s and called it a hydraulic motor. Waterwheels were replaced by turbines and then the focus was to exploit hydro power for large-scale supply of electricity.

Pelton wheel (or turbine) is a high head tangential flow impulse turbine developed in 1870s by an American engineer, L.A. Pelton. In India these turbines are installed in hydro plants at Koyna, Shravathi, Joginder Nagar, Pallivasal and Pykra [8,9].

Francis turbine is a mixed flow reaction turbine developed by J. B. Francis, an American engineer, and his team at Lowell, Massachusettsin in 1848. In the following years, Francis turbine was the most widely used turbine. These turbines are installed in India in hydro plants located at Bhakra, Siva Samudaram, GanghiSagar, Hirakud and Rihand.

The growing demands of higher capacity, velocity and efficiency led to the development of the Kaplan turbine – an axial flow reaction turbine patented by an Austrian engineer, V. Kaplan in 1913. Hydro plants, in India, located at Hirakud, Tungabhadra, Kohlapur and NizamSagar use these turbines.

In impulse turbines the water energy is entirely converted into kinetic energy. The high speed water jet enters the turbine at atmospheric pressure. Therefore, the turbine is not pressure tight. In a reaction turbine, on the other hand, the entering water jet has kinetic energy as well as pressure energy as it enters the turbine impeller. Therefore, the turbine is pressure tight. Consequently, the manufacturing cost of reaction turbines is higher. In addition to the above turbines, Turgo turbines are impulse type and the propeller turbine is a reaction type. Pelton, Francis and propeller (a variant of Kaplan) find applications in hydropower plants. The criteria for the choice of the most suitable and efficient turbine for an application are the head and the flow rate [1, 6, 12].

Teaching of Concepts of Hydraulic Machines

The Lucknow Campus of Amity University [11] is situated in the state of Uttar Pradesh in India. Hydropower is taught in the 'Advanced Fluid Mechanics' course in the sixth semester of the eight semester undergraduate B. Tech. (Mechanical and Automation Engineering) programme. The prerequisites of the advanced course are 'Basic Fluid Mechanics' and a course in engineering mathematics. The theoretical input of the course includes impact of jets, Euler's equation of hydrodynamic machines, hydraulic turbines (Pelton, Francis and Kaplan) and their performance parameters, specific speed and unit quantities, selection and governing of turbines, pumps and performance characteristics, cavitation, hydraulic transmission and hydraulics. The course is taught over 70 hours of lectures. The additional weekly laboratory

sessions include performance analysis of Pelton, Francis & Kaplan turbines, centrifugal pumps, and a set up for study of cavitation, pipe friction and hydraulic control.

The taught and practical sessions are run such that theory is taught before experiments are performed in the laboratory. The normal sequence of activities includes a theory class followed by a laboratory experiment and its analysis and numerical exercises covering the taught theoretical concepts. Basics of a hydraulic turbines are given in the annexure-I.

Performance Evaluation

Modeling, simulation and practical evaluation are the three approaches for the performance assessment. Modeling of hydraulic plants has been done [13] for linear and non-linear systems with elastic and non-elastic water column by using transfer function approach. With numerical techniques and increased processing speed of computers, simulation has been used for performance predictions as well as for research and development by using CFD in packages such as ANSYS/CFX [14, 15]. These approaches require validation using practical or experimental data. Mathematical modeling of the type such as hydraulic transmission and actuation system [16, 17] enables to simulate performance by varying each hydraulic length, diameter and geometry, which is difficult in the context of a prime mover.

Tyagi [18] has verified experimentally and theoretically variations of flow rate, water level, power and angle of incidence including different liquids in Pelton turbine. Agar and Rasi [17] analyzed the data based on student experiments on Pelton turbine in laboratory. Analysis included variation of tangential force, speed, and mechanical efficiency. A variation of tangential force with speed of rotation was represented by fitted linear equation.

Gudukeya et al [20] studied the effect of surface roughness, hardness of material on turbine efficiency. Efficiency also depends on mounting of water jet in a Pelton turbine.

Present Work

Normally characteristic curves are drawn for knowing the behavior and performance of the turbine under different working conditions. Various performance parameters are Speed (N), Head (H), Discharge (Q), Power (P), and overall efficiency. Out of these three are independent parameters (N, H & Q), one parameter is kept constant and variation of other parameters with respect to other two independent variables (say N and Q) are plotted and various curves are obtained. In the present work, laboratory experimental data has been used to analyze water power utilized against the shaft power demand and variation of overall efficiency, specific speed, unit speed, unit power and unit discharge has been analyzed. All of the three Pelton, Francis and Kaplan small turbines have been used.

Experimental Set Up and Data

Water head is created by running a Centrifugal pump. Flow rate was measured by differential pressure across an orifice. Pressure head is measured by using a pressure gauge at inlet. Speed was measured by a Tachometer. Brake power was computed by using Rope Brake Dynamometer using pulley, rope, weight and spring balance. Manual governing was done.

Schematic of a Hydro Turbine in a Block Diagram

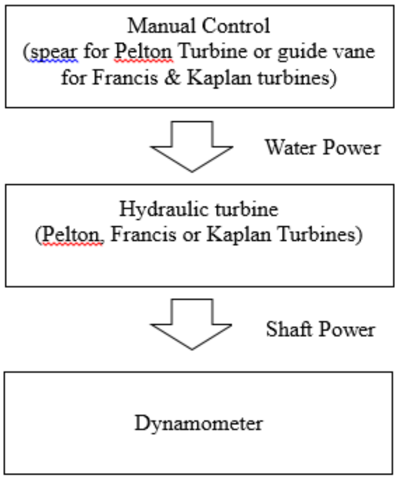


Figure 1: Block Diagram of the Schematic of a Hydro Turbine

Turbine Design Details

Turbine design details are given in the following table.

Table 2: Design Details of Small Turbines

Turbine	Pelton	Francis	Kaplan
Supply head m	46	15	5
Discharge lpm	80	1500	1500
Speed rpm	1500	1500	1500
Power Output Kw	3.75	3.75	3.75
Pitch circle diameter mm & Jet diameter mm	260 & 22	-	-
Runner inner/ outer diameter mm	-	127/ 160	110/ 200
Number of buckets/ vanes	18	8	4
Number of guide vanes	-	10	16

METHODOLOGY

A centrifugal pump is used to create water head for the turbine. The speed of turbine is set manually by a spear at nozzle in case of Pelton turbine or by guide vanes in case of Francis and Kaplan turbines. The speed of the turbine is measured by a tachometer. A resisting torque is applied through the pulley of a dynamometer which causes the speed of the turbine to reduce due to the applied load. The water power is then increased (by manual adjustment as above) to bring back the turbine to the same speed.

DISCUSSIONS AND CONCLUSIONS

During the laboratory experiments, the speed of turbines ranged from 1080 RPM to 1930 RPM, water head ranged from 5.5 m to 52 m and load varied from 0.53 KW to 1.9 KW for all the three turbines combined. Shaft power ratio (SPR), a non-dimensional quality is the ratio of shaft power demand and rated capacity 3.75 KW, which is same for all these Pelton, Francis and Kaplan small turbines and likewise Water Power Ratio (WPR) is the ratio of water power utilized, to meet the shaft power demand, and rated capacity of turbines.

Figure 2 shows the variation of WPR with SPR for all the turbines. WPR increases with increase in SPR and it exceeds 100% at SPR above 20%. It is due to overall efficiency being below 20% at lower demands in case of Pelton turbine, in case of Francis turbine, initially, it is constant up to 27% of shaft load then it increase up to 36% of load and then it decreases. In Kaplan it has increasing trend within the range of data analyzed.

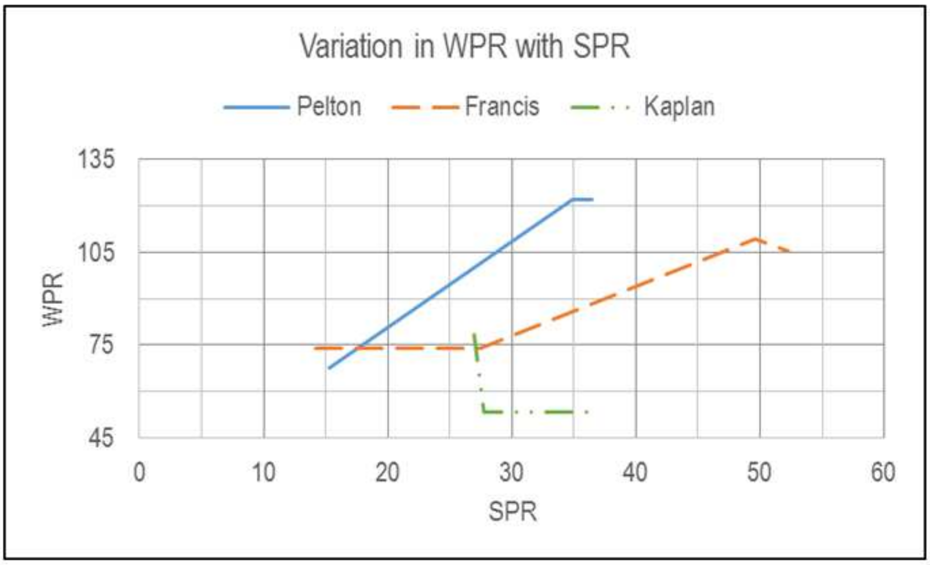


Figure 2: Ariation of WPR with SPR

Figure 3 shows the variation of overall efficiency with SPR. Overall efficiency increases in case of Pelton turbine. For Francis turbine, it increases with increasing shaft load up to 27 % and then increase is less steep, whereas for Kaplan turbine, it is initially a sharp increase and subsequently less steep.

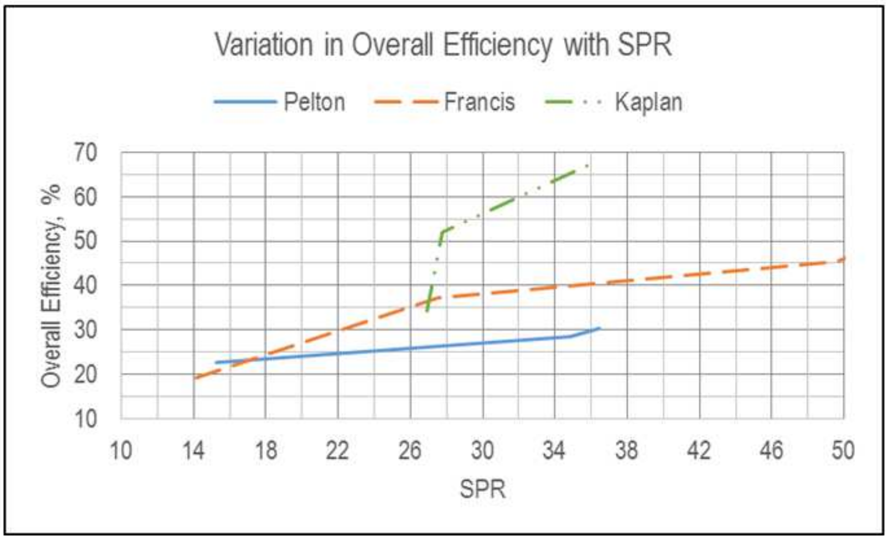


Figure 3: Variation of Overall Efficiency with SPR

Figure 4, shows the variation of SPR with specific speed. In case of Pelton turbine and Francis turbine, specific speed increases continuously with shaft power demand whereas for Kaplan turbine it has initial steep increase then slow creasing trend.

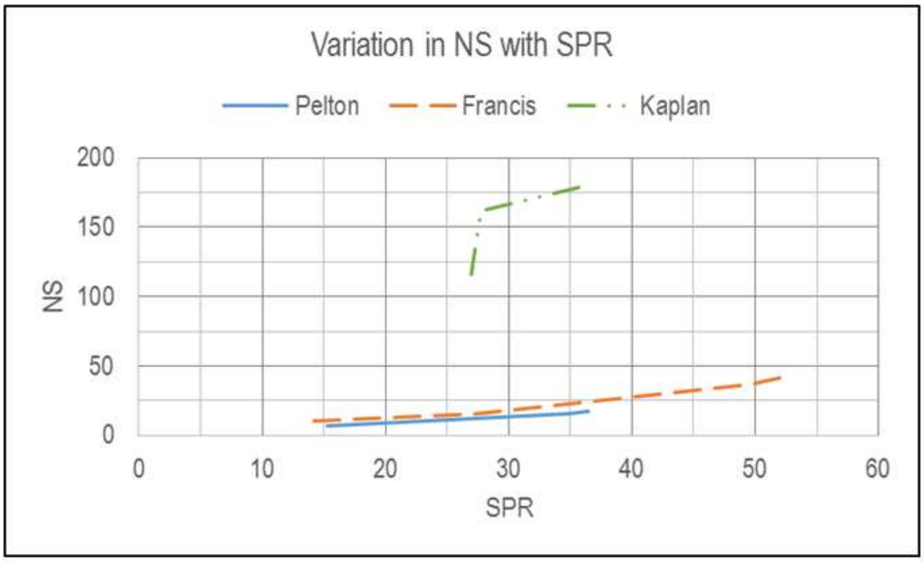


Figure 4: Variation of SPR with Specific Speed

Figures 5 shows the variations of unit quantities with shaft power load (SPR). All the unit quantities have increasing trend with increasing shaft power demand (SPR) in all the turbines.

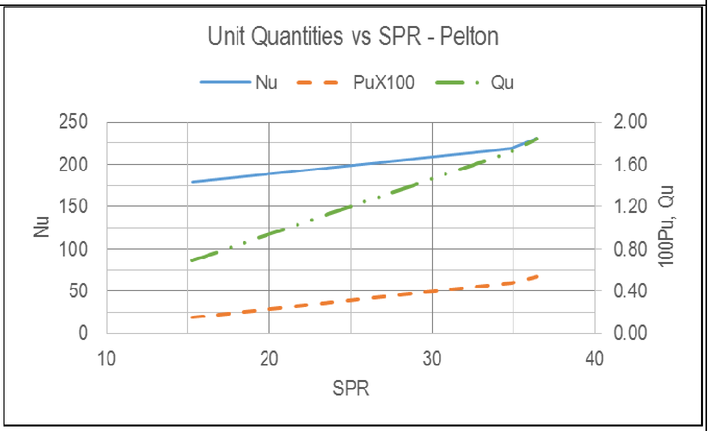
Unit speed has increasing trend in case of Pelton and Francis turbines as compared to that in Kaplan turbine.

Unit power has increasing trend in all the three turbines.

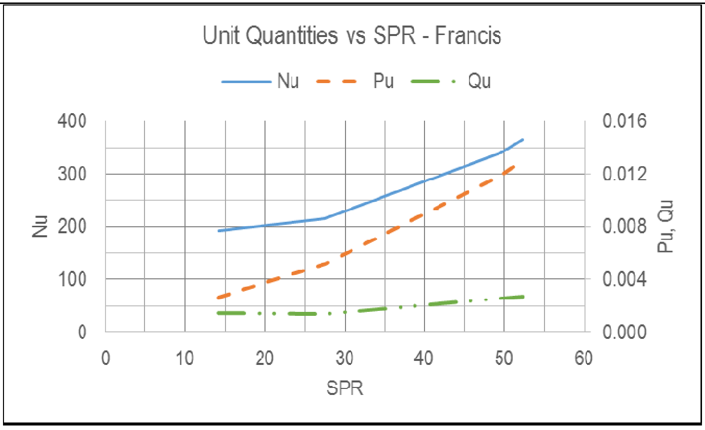
Unit discharge has increasing trend in case of Pelton turbine where as comparatively it is steady in case of Francis and Kaplan turbines.

Over all unit quantities are not much effected with power demand changes in case of Kaplan turbine.

Pelton



Francis



Kaplan

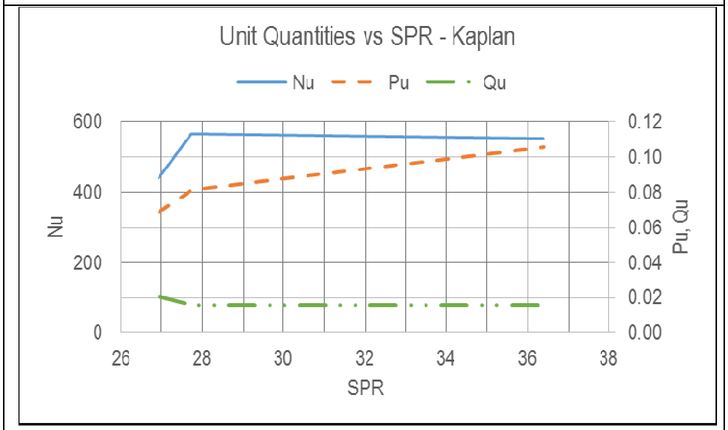


Figure 5: Variation of Unit Quantities with Shaft Load (SPR)

Maximum efficiency recorded during this analysis was 33.3 % for Pelton turbine, 49.5 % for Francis turbine and 68 % for Kaplan turbine.

This analysis is based on assorted data recorded during laboratory experiments for computation of overall efficiency of Pelton, Francis and Kaplan turbines. Further studies can be done to generate more data to arrive on trend and pattern of various turbine parameters.

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APPENDICES

Annexure-I

Basics of a Hydraulic Turbine

The power available from an effective head (H) is given by [12],

$$P = W.H \qquad \text{(Equation 1)}$$

where W is the weight of water flowing through the system per second.

Power output is the shaft power measured with the help of a dynamometer and is given by,

$$SP = \frac{2\pi NT}{60} \qquad \text{(Equation 2)}$$

Where N is the shaft revolution per minute and T is the torque applied on shaft as load given by, T = Load × Drum Radius.

$$Overall\ Efficiency, \eta_o = \frac{SP}{P} \times 100 \qquad \text{(Equation 3)}$$

Specific speed is a criteria for selection of type of turbine and is given by

$$N_S = \frac{N.P^{\frac{1}{2}}}{H^{\frac{5}{4}}} \qquad \text{(Equation 4)}$$

Unit quantities (Power, Discharge and Speed) are useful in predicting off-design performance of a turbine and are expressed as,

$$N_S = \frac{N.P^{\frac{1}{2}}}{H^{\frac{5}{4}}} \qquad \text{(Equation 5)}$$

$$Unit\ Discharge, Q_u = \frac{Q}{\sqrt{H}} \qquad \text{(Equation 6)}$$

$$Unit\ Power, P_u = \frac{P}{\sqrt{H^3}} \qquad \text{(Equation 7)}$$